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PHOTONUCLEAR REACTIONS AT LAWRENCE LIVERMORE NATIONAL LABORATORY 1984

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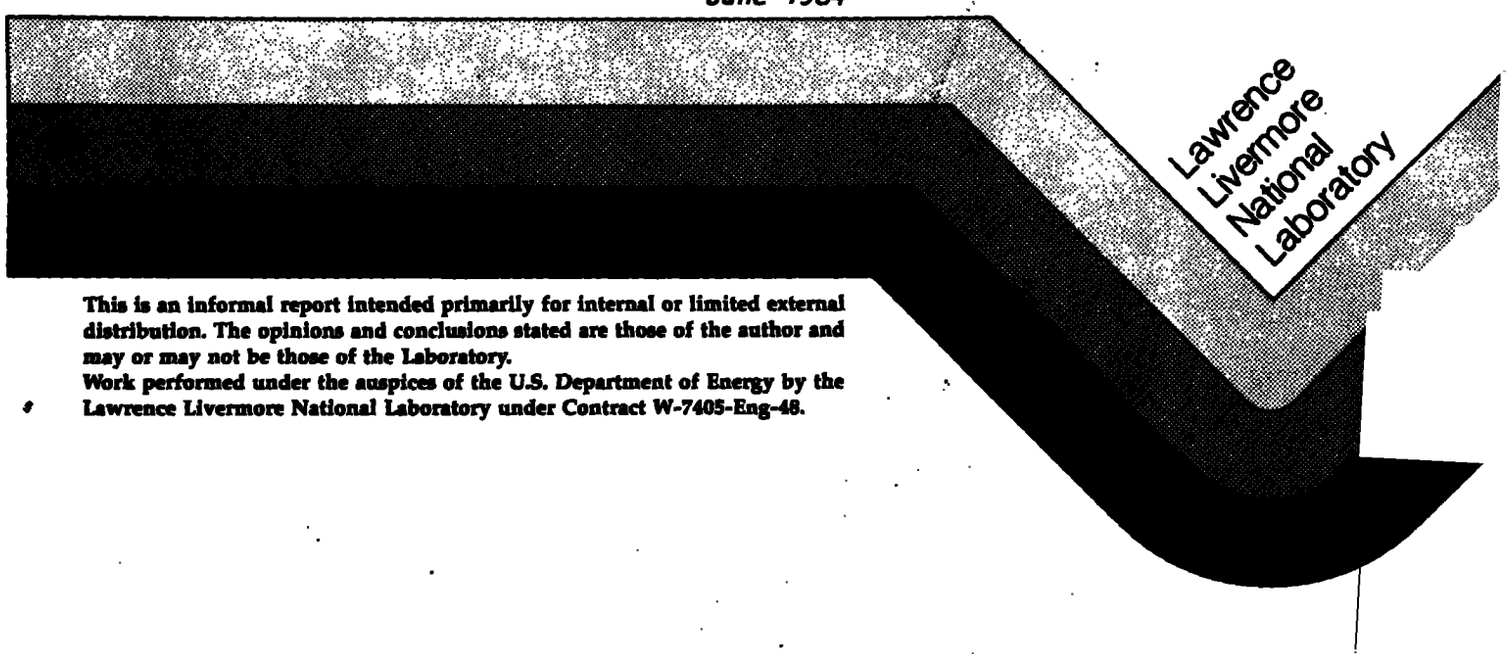
June 1984



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Photonuclear Reactions at Lawrence Livermore National Laboratory

Compiled by B. L. Berman

Since the 1982 Gordon Conference on Photonuclear Reactions (see LLNL Report No. UCID-19391), the photonuclear work that has been done at LLNL has featured photoneutron and photoproton cross-section measurements (on ^{14}C and ^{17}O, respectively). In addition, collaborative experiments have been pursued at M.I.T. [(e,e') measurements], L.B.L. (electromagnetic-dissociation mesurements), and T.U.N.L. [$(\vec{n},\gamma)$ measurements].

Since the 1982 Gordon Conference, 14 papers have been published and 6 more have been submitted for publication. A listing of these is given here, which includes as well 4 abstracts that report results not represented in the published or submitted papers.

Abstracts or short summaries of work submitted for publication or currently in progress, interspersed with figures of representative data, follow. Included among the papers listed here are some that have resulted from collaborative efforts with colleagues at the Universities of New Hampshire, Virginia, Trent, Melbourne, Saskatchewan, Toronto, São Paulo, Indiana. Georgia, Florida State, Mainz, Massachusetts, and Stanford, Los Alamos National Laboratory, and C.E.N. de Saclay, in addition to the Laboratories noted above.

Finally a fourth edition of the Atlas of Photoneutron Cross Sections Obtained with Monoenergetic Photons, expanded to include plots of integrated cross sections and their moments, is in preparation.

Papers Published in Refereed Journals

J. R. Calarco, B. L. Berman, and T. W. Donnelly
Implications of the Experimental Results on the Photodisintegration of ^{4}He
Phys. Rev. C 27, 1886 (1983).

R. W. Lourie, W. Bertozzi, T. N. Buti, J. M. Finn, F. W. Hersman, C. Hyde, J. Kelly, M. A. Kovash, S. Kowalski, M. V. Hynes, B. E. Norum, and B. L. Berman
Inelastic Electron Scattering from ^{9}Be
Phys. Rev. C 28, 489 (1983).

J. G. Woodworth, R. A. August, N. R. Roberson, D. R. Tilley, H. R. Weller, and J. W. Jury
Polarized Neutron Capture into ^{13}C: Evidence for a Secondary Doorway State Effect
Phys. Rev. C 29, 1186 (1984).

J. W. Jury, B. L. Berman, J. G. Woodworth, M. N. Thompson, R. E. Pywell, and K. G. McNeill
Photoneutron Cross Sections for ^{15}N
Phys. Rev. C 26, 777 (1982).

B. L. Berman, R. Bergère, and P. Carlos
Integrated Photonuclear Cross Section for ^{16}O
Phys. Rev. C 26, 304 (1982).

B. L. Berman, J. W. Jury, J. G. Woodworth, R. E. Pywell, K. G. McNeill, and M. N. Thompson
Photoneutron Cross Section for ^{16}O
Phys. Rev. C 27, 1 (1983).

R. E. Pywell, B. L. Berman, J. W. Jury, J. G. Woodworth, K. G. McNeill, and M. N. Thompson
Photoneutron Cross Sections for the Silicon Isotopes
Phys. Rev. C 27, 960 (1983).

G. Odgers, B. L. Berman, R. E. Pywell, and M. N. Thompson
Photoneutron Cross Section for ^{30}Si
Nucl. Phys. A388, 445 (1982).

J. D. T. Arruda-Neto, S. B. Herdade, I. C. Nascimento, and B. L. Berman
Electrofission of ^{234}U, ^{236}U, and ^{238}U: Angular Distributions and E2 Strength Functions
Nucl. Phys. A389, 378 (1982).

J. D. T. Arruda-Neto, S. B. Herdade, I. C. Nascimento, and B. L. Berman
Concentration of E2 Strength near the Fission Barrier of $^{234,236,238}U$
Rev. Bras. Fis. 13, 122 (1983).

M. Blann, B. L. Berman, and T. T. Komoto
Precompound-Model Analysis of Photonuclear Reactions
Phys. Rev. C 28, 2286 (1983).

A. Goldberg

On the Virtual Photon Spectrum for Electromagnetic Dissociation of Relativistic Nuclei in Peripheral Collisions

Nucl. Phys. (in press).

B. L. Berman

Nuclear Giant Resonances - A Historical Review

Festschrift for Edward Teller (in press).

Papers Published in Conference Proceedings

B. L. Berman

Electromagnetic Dissociation of Radioactive Heavy-Ion Beams

Proc. Workshop on Prospects for Research with Radioactive Beams from Heavy-Ion Accelerators (Washington, D.C., 1984), in press.

Papers Submitted to Refereed Journals

R. E. Pywell, B. L. Berman, J. G. Woodworth, J. W. Jury, K. G. McNeill, and M. N. Thompson

Photoneutron Cross Sections for ^{14}C

Phys. Rev. C

J. Kelly, M. V. Hynes, W. Bertozzi, T. N. Buti, J. M. Finn, F. W. Hersman, C. Hyde-Wright, M. A. Kovash, B. Murdock, B. E. Norum, B. Pugh, F. N. Rad, A. D. Bacher, G. T. Emery, C. C. Foster, W. P. Jones, D. W. Miller, B. L. Berman, W. G. Love, J. A. Carr, and F. Petrovich

Density Dependence in the Two-Nucleon Effective Interaction at 135 MeV

Phys. Rev. C

D. Rowley, T. W. Phillips, J. G. Woodworth, J. W. Jury, and J. D. Watson

Ground State Photoneutron Reactions in ^{17}O

Phys. Rev. C

J. Kelly, W. Bertozzi, T. N. Buti, J. M. Finn, F. W. Hersman, C. Hyde, M. V. Hynes, M. A. Kovash, B. Norum, J. Pekar, F. N. Rad, A. D. Bacher, G. T. Emery, C. C. Foster, W. P. Jones, D. W. Miller, B. L. Berman, W. G. Love, and F. Petrovich

Neutron Transition Density for the Lowest 2^+ State of ^{18}O

Phys. Rev. Lett.

H. Miessen, H. Rothhaas, G. Lührs, G. A. Peterson, R. S. Hicks,
R. A. Lindgren, B. L. Berman, S. Kowalski, and C. P. Williamson
Elastic Magnetic Electron Scattering from ^{29}Si and ^{31}P
Nucl. Phys.

K. A. Griffioen, P. J. Countryman, K. T. Knöpfle, K. Van Bibber,
M. R. Yearian, J. G. Woodworth, D. Rowley, and J. R. Calarco
Coincidence Electron Scattering (e,e'f) and Multipole Strength Functions
in ^{238}U
Phys. Rev. Lett.

Published Abstracts of Other Work

T. N. Buti, W. Bertozzi, J. M. Finn, W. Hersman, C. Hyde, J. Kelly, M. A. Kovash, S. Kowalski, R. Lourie, B. Murdock, B. Pugh, F. N. Rad, C. P. Sargent, W. Turchinetz, B. Norum, B. L. Berman, and M. Hynes

Electron Scattering from Isoscalar States in ^{16}O

Bull. Am. Phys. Soc. 28, 673 (1983).

C. Hyde-Wright, W. Bertozzi, T. N. Buti, M. Finn, M. A. Kovash, R. Lourie, B. Murdock, B. Pugh, P. Ulmer, B. L. Berman, W. Hersman, M. V. Hynes, J. J. Kelly, B. Norum, A. D. Bacher, G. Emery, C. C. Foster, W. Jones, and D. Miller

Inelastic Electron and Proton Scattering Excitation of the First 2^- State in ^{16}O

Bull. Am. Phys. Soc. 28, 691 (1983).

S. Simionatto, J. D. T. Arruda Neto, S. B. Herdade, Z. Carvalheiro, and B. L. Berman

Fotofissão do ^{233}U

Soc. Bras. Prog. Ciência 35, 307 (1983)

J. D. T. Arruda Neto, S. B. Herdade, and B. L. Berman

Decaimento por Fissão de Níveis 1^+ em Núcleos Actinídeos

Soc. Bras. Prog. Ciência 35, 307 (1983).

Photoneutron Cross Sections for ^{14}C

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Using monoenergetic photons, the cross sections for the (γ,n) and $(\gamma,2n)$ reactions in ^{14}C have been measured from threshold to 36 MeV. There is little evidence of a pygmy resonance (a peak at 11.2 MeV probably is an M1 transition). At 15.5 MeV, a prominent peak may represent the maximum of the $T_<$ GDR. The (γ,n) cross section has a valley centered around 26 MeV, coincident with the major peak in the $(\gamma,2n)$ cross section; this is probably near the location of the $T_>$ GDR. Other features are interpretable in terms of the opening of the (γ,p) and (γ,np) channels and the opening of $T_>$ states in ^{13}C. The expected isospin splitting of the GDR of ^{14}C is 8.6 MeV; this is consistent with the above interpretation of the 15-MeV peak in the (γ,n) cross section and the peak in the $(\gamma,2n)$ cross section. The (γ,p) cross section (threshold 20.8 MeV) is expected to be large from sum-rule considerations, and also will result mainly from decay of the $T_>$ GDR. This interpretation is consistent with recent theoretical calculations.

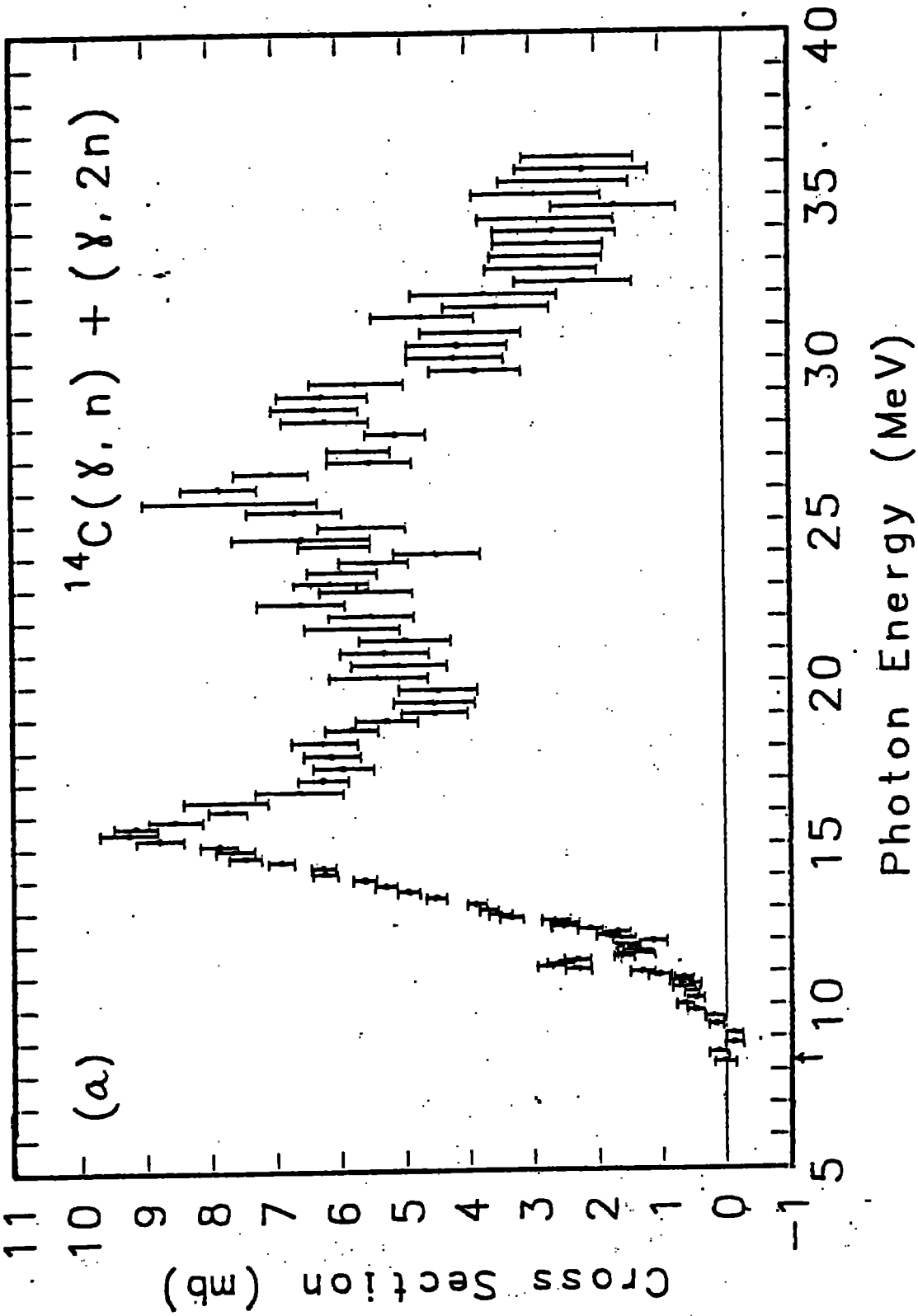
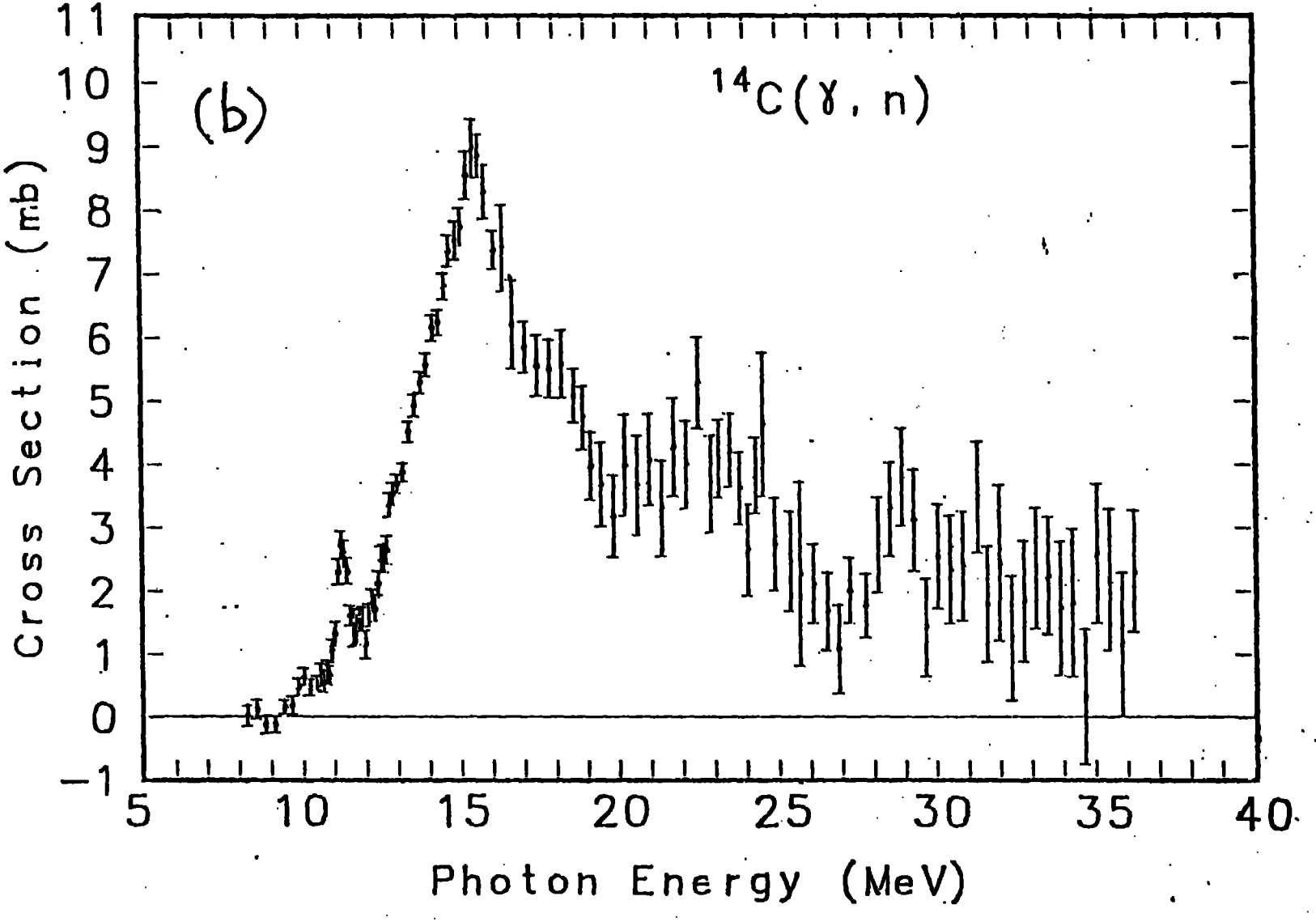
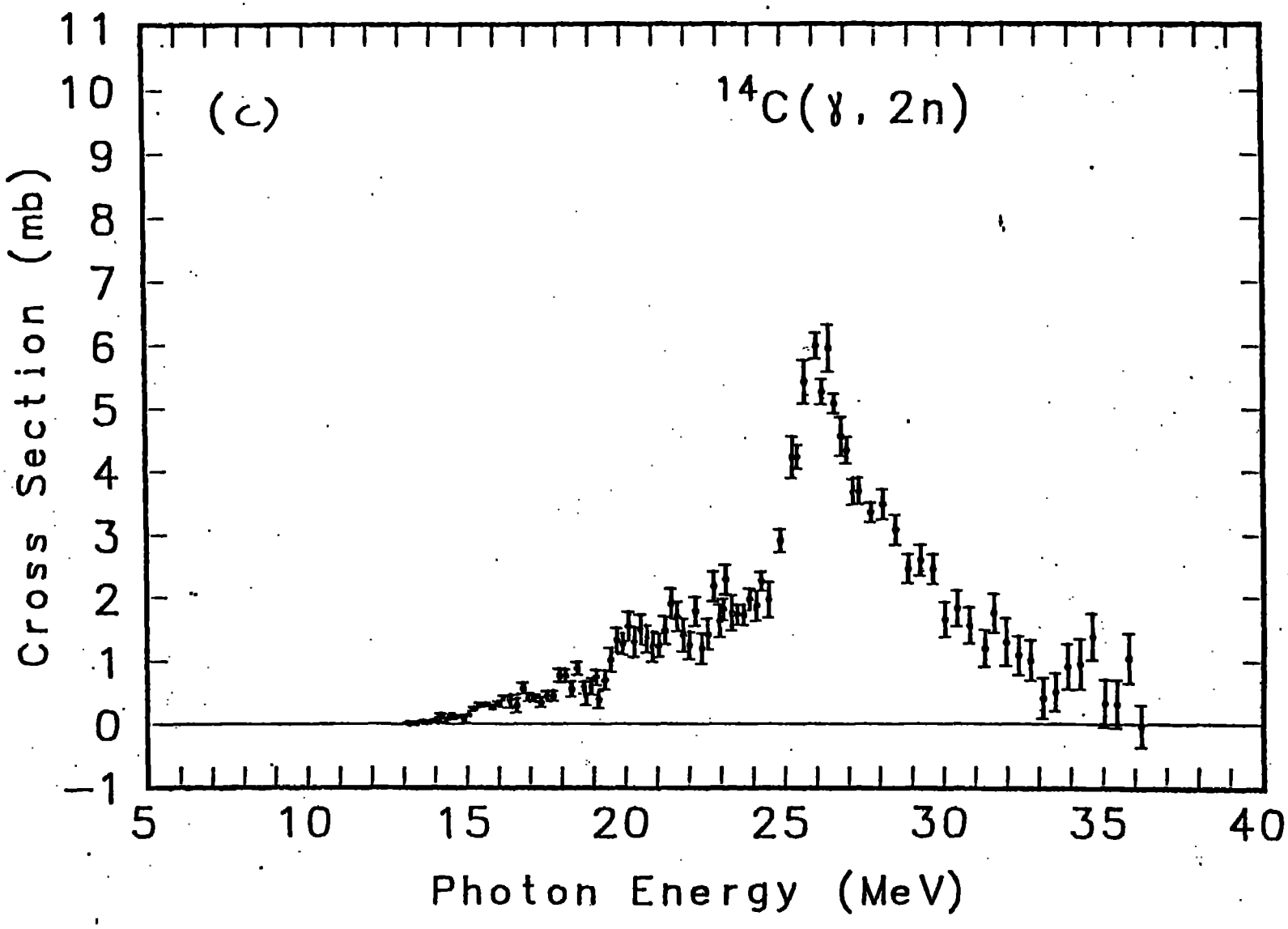


Fig. 1 The (a) total, (b) single, and (c) double photoneutron cross sections for ^{14}C


(b)
$^{14}C(\gamma, n)$
Cross Section (mb)
Photon Energy (MeV)
11
10
9
8
7
6
5
4
3
2
1
0
−1
5
10
15
20
25
30
35
40


(c)
$^{14}C(\gamma, 2n)$
Cross Section (mb)
Photon Energy (MeV)
11
10
9
8
7
6
5
4
3
2
1
0
−1
5
10
15
20
25
30
35
40

Density Dependence in the Two-Nucleon Effective Interaction at 135 MeV

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Differential cross sections and analyzing powers for scattering of 135-MeV protons by ^{16}O have been measured for all narrow states below 12.1 MeV of excitation up to a momentum transfer of 3.2 fm^{-1}. An extensive microscopic analysis of the data for normal-parity transitions has been performed. The proton transition densities are taken from phenomenological fits to electron-scattering data that extend to a momentum transfer of 2.6 fm^{-1}. Charge symmetry is invoked to equate the neutron and proton transition densities. Therefore, the microscopic analysis is interpreted as a test of the two-nucleon effective interation in the nuclear medium with minimal complication by nuclear-structure uncertainities.

Definitive evidence for strong density dependence in the isoscalar spin-independent central component of the two-nucleon effective interaction near 150 MeV has been found. The signatures of density dependence are clear and strong. The differential cross sections show that relative to the free two-nucleon interaction the low- (high-) momentum-transfer strength of the central component of the effective interaction in the nuclear medium is suppressed (enhanced) as the density increases. The analyzing powers exhibit strong negative excursions near 2.6 fm^{-1}, which support the enhanced repulsion at high density.

The inelastic-scattering data are very well described by the local-density approximation, which employs the nuclear-matter effective interaction appropriate to the density in the vicinity of the interacting nucleons.

The data are sensitive to the differences between effective interactions based on the Paris and Hamada-Johnston potentials, and would be improved by an intermediate interaction.

Ground State Photoneutron Reactions in ^{17}O

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Photoneutron angular distributions and differential cross sections have been measured for the reaction $^{17}O(\gamma,n_0)^{16}O$ over the excitation energy region from 10 to 24 MeV. The angle-integrated ground state cross section was obtained and compared to the total photoneutron cross section. The comparison indicates that the ground state channel dominates the pygmy resonance region below E_γ = 16 MeV but contributes very little (<10%) to the giant resonance region (near 22 MeV). Legendre coefficients extracted from the angular distribution data suggest that electric dipole transitions make up nearly all of the absorption strength in the region studied except in narrow regions near 10.8, 15.1, 17.3 and 22.3 MeV where small but significantly non-zero values of the a_1 coefficient are observed. Values of the a_2 coefficient, interpreted in an E1 approximation, suggest a relatively pure single-particle composition of many of the states observed in the pygmy resonance region from 10 to 16 MeV.

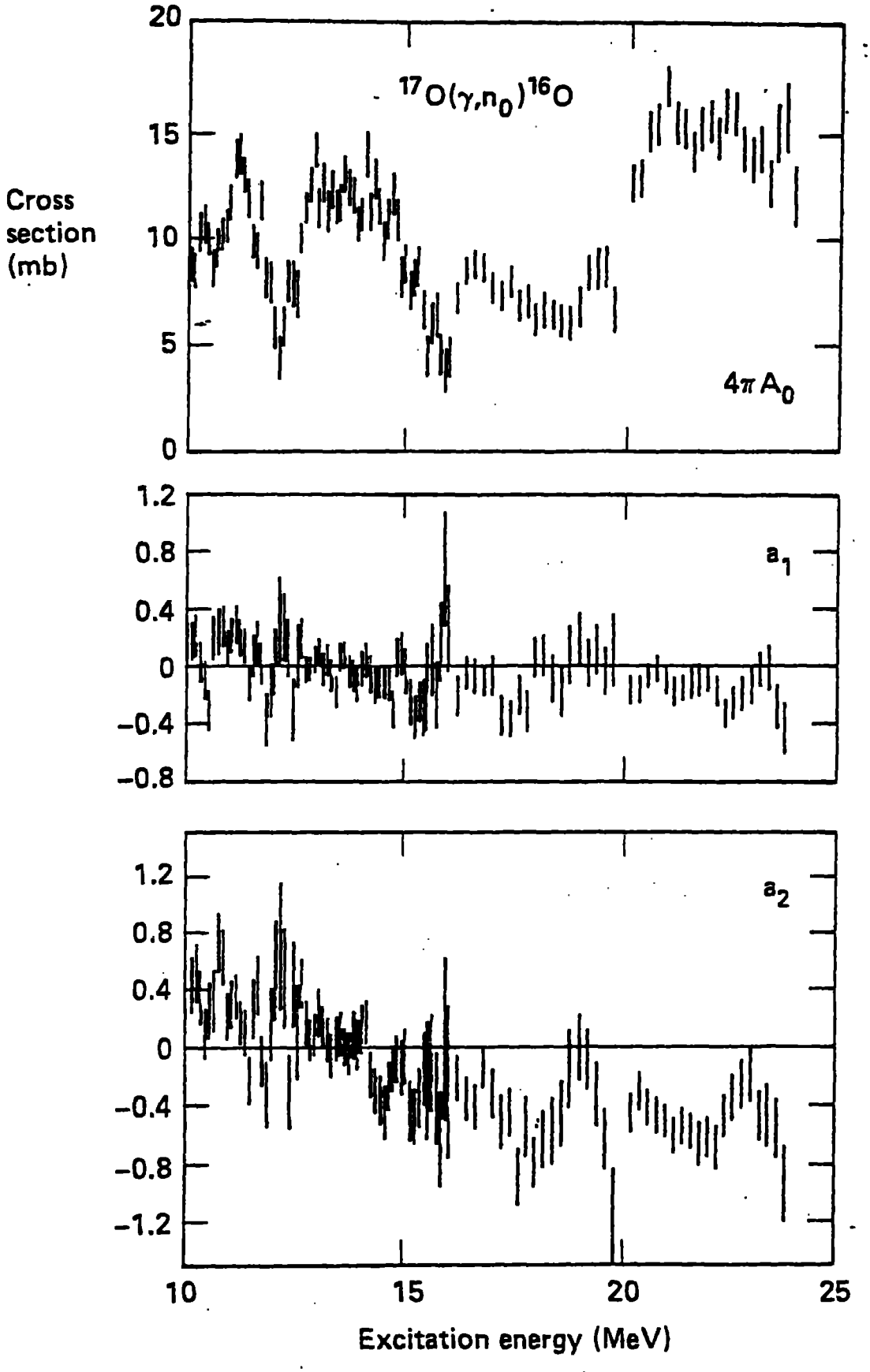

Fig. 2 The angle-integrated ground state cross section ($4\pi A_0$) is plotted vs. excitation energy. Also shown are the normalized anisotropy coefficients a_1 and a_2 from a Legendre polynomial fit.

Photoproton Cross Section for ^{17}O

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The $^{17}O(\gamma,p)$ cross section has been measured with monoenergetic photons and photoactivation at the LLNL Electron-Positron Linear Accelerator. In this cross section we observed a remarkably large and narrow resonance at an excitation energy of 15.1 MeV, and two smaller resonances at 18.0 and 19.3 MeV. These resonances do not appear in the (γ,n) reaction channel for ^{17}O, whose cross section we measured previously. This fact, together with the values of their excitation energies and the energy, spin, and parity of the states in ^{16}N to which they decay and of related states in neighboring nuclei, points to the possibility that the 15-MeV resonance might be an unresolved doublet, and that the resulting two pairs of isovector states might then constitute corresponding sets of non-spin-flip and spin-flip states excited by electric-dipole radiation.

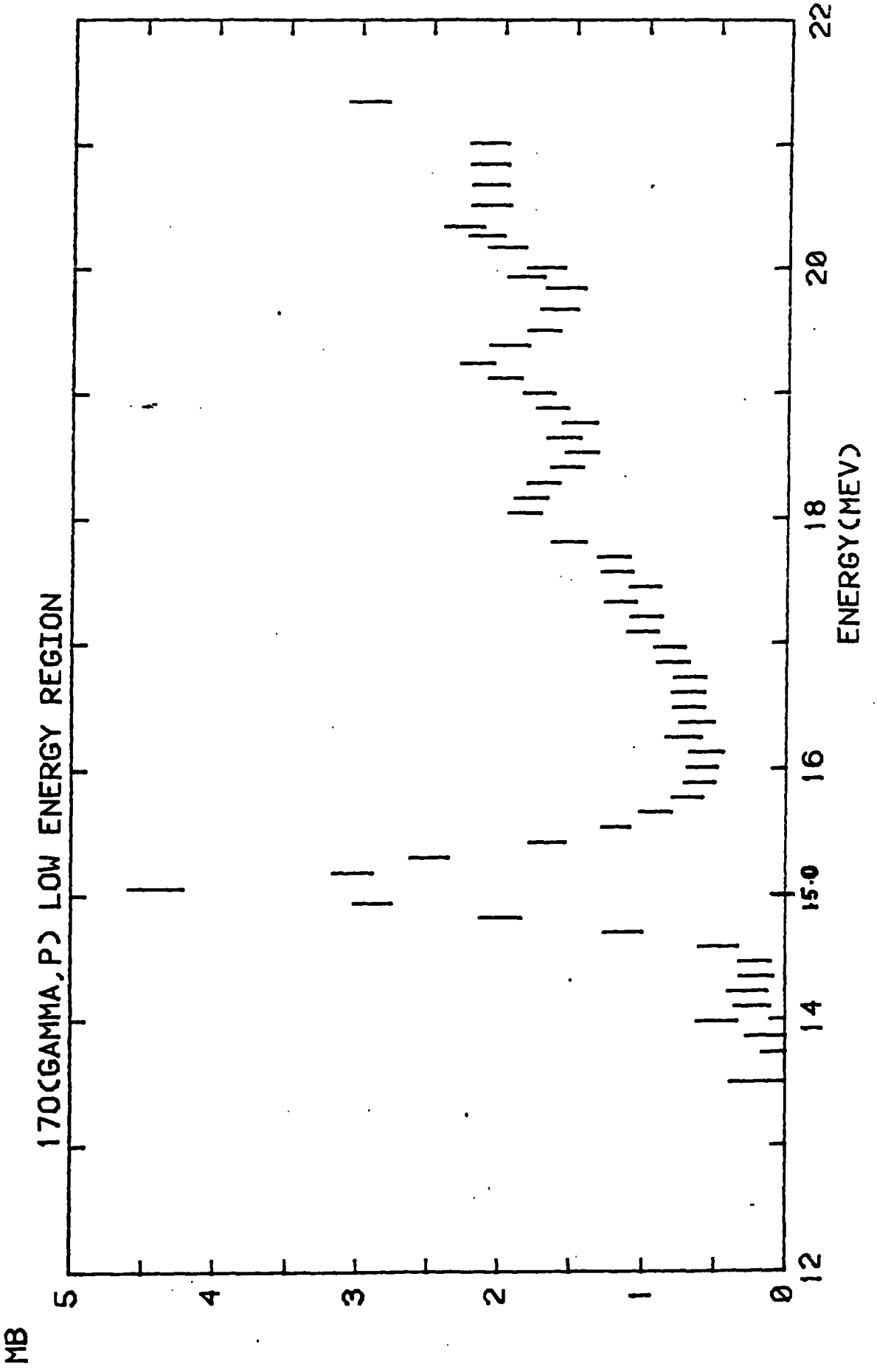

Fig. 3 The $^{17}O(\gamma,p)$ cross section in the photon-energy region from threshold to 21 MeV.

Neutron Transition Density for the Lowest 2^+ State of ^{18}O

J. Kelly, W. Bertozzi, T. N. Buti, J. M. Finn, F. W. Hersman, C. Hyde, M. V. Hynes, M. A. Kovash, B. Norum, J. Pekar, and F. N. Rad
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Scattering of 135 MeV protons is used to study the neutron transition density of the first 2^+ state of ^{18}O. The proton density is taken from a fit to (e,e') data. The local density approximation and a nuclear matter effective interaction are used. The results are consistent with electromagnetic decay data for the mirror transition in ^{18}Ne. The transition radius is larger for neutrons than for protons.

Elastic Magnetic Electron Scattering from ^{29}Si and ^{31}P

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Cambridge, Massachusetts 02139, USA

Elastic magnetic electron-scattering form factors for ^{29}Si and ^{31}P have been measured in the range of momentum transfer from 1.0 to 2.8 fm^{-1}. Analysis of the data using a particle-core-coupling model yields $2s_{1/2}$ occupation probabilities for the valence nucleon of 0.46±0.01 for the neutron in ^{29}Si and 0.48±0.01 for the proton in ^{31}P. The radius of the $2s_{1/2}$ proton orbit in ^{31}P has been found to be $5.3^{+2.6}_{-1.5}$ % larger than the corresponding neutron orbit in ^{29}Si. Recent large-basis shell-model calculations of the form factors do not accurately reproduce the experimental results.

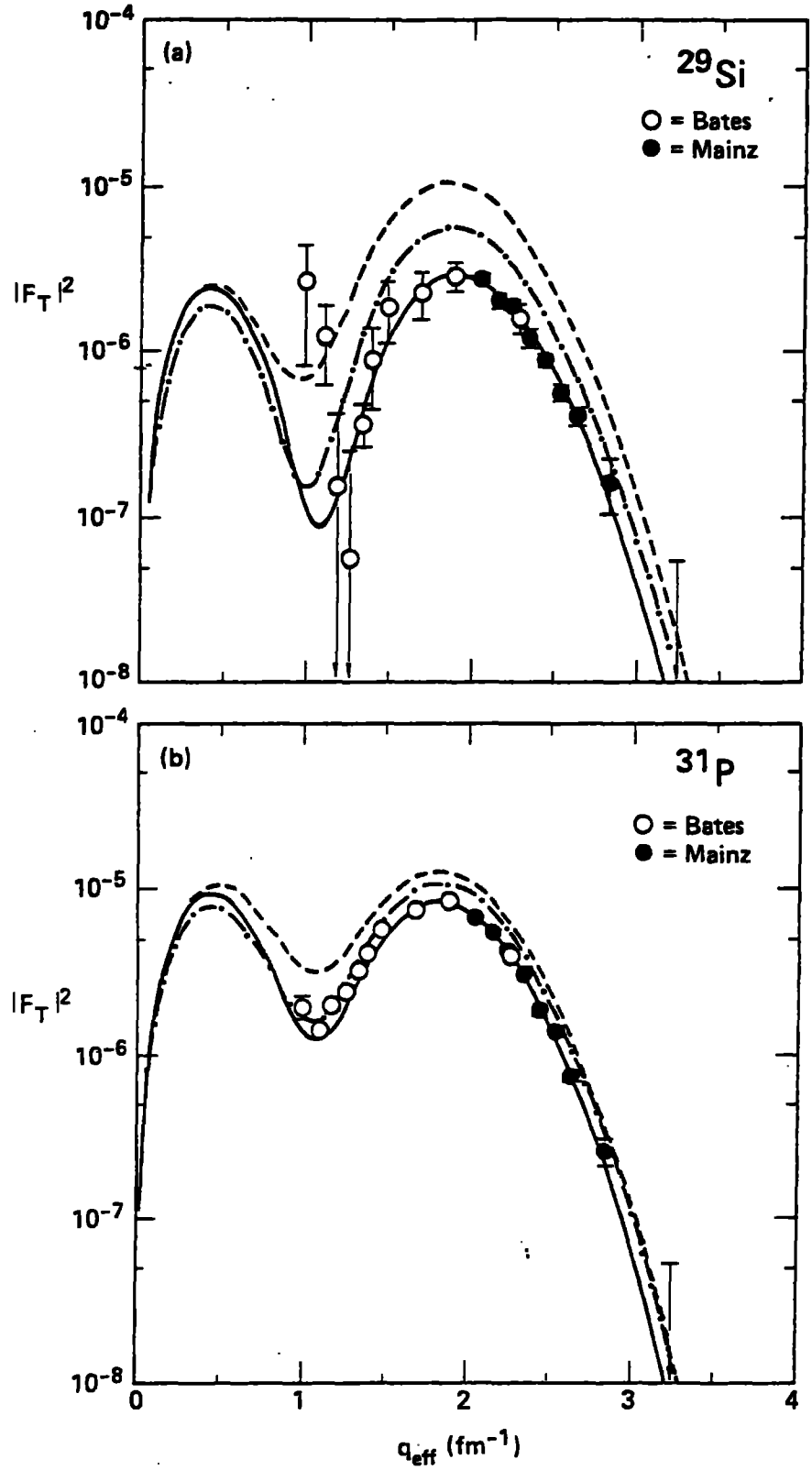

Fig. 4 The measured squared transverse form factors for (a) ^{29}Si and (b) ^{31}P, together with theoretical fits to the data obtained from recent large-basis shell-model calculations (dashed and dot-dashed curves). Our ICM best fits (solid curves) are shown here for comparison purposes.

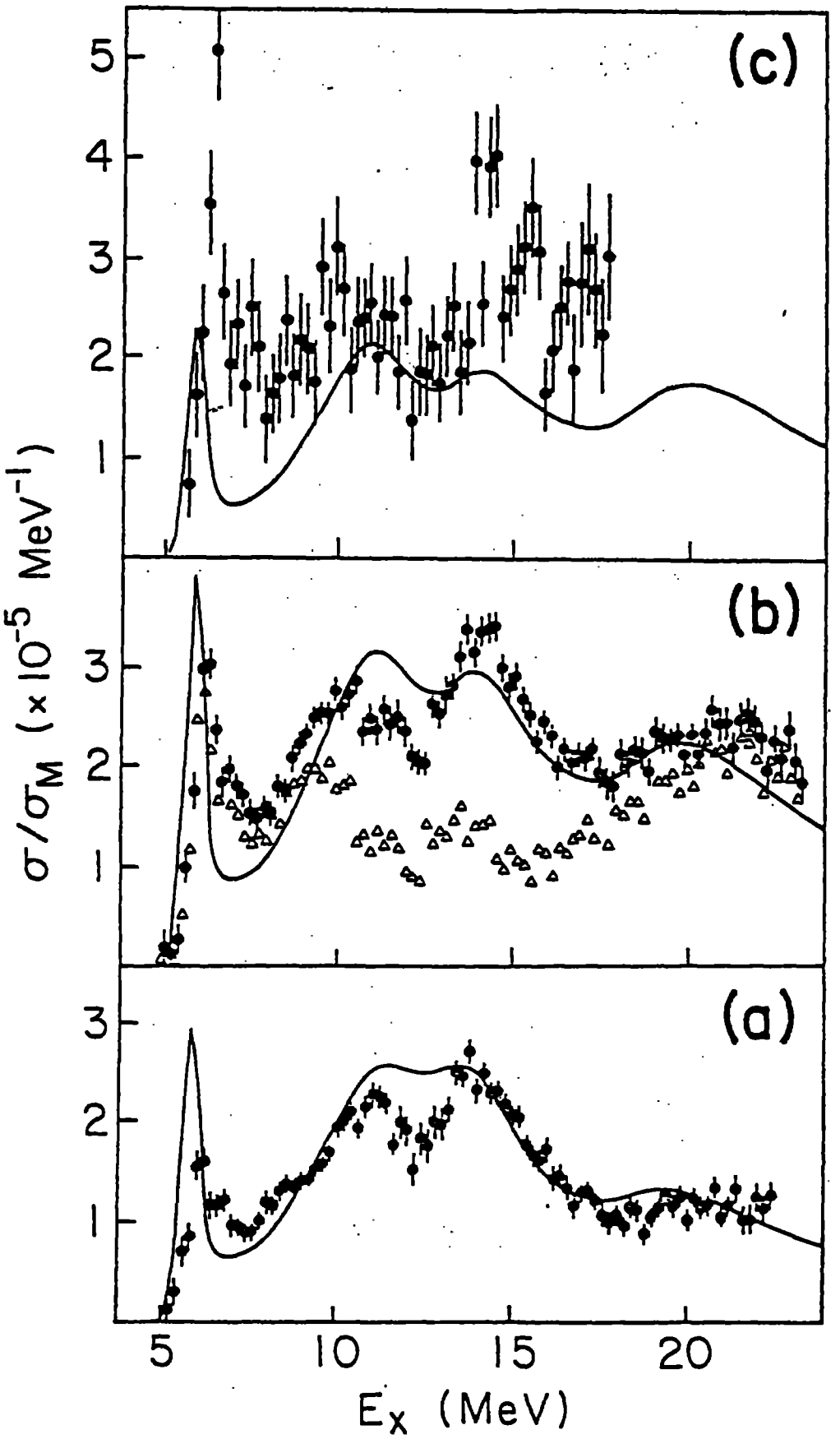

Fig. 5 The doubly differential $^{238}U(e,e'f)$ cross sections divided by the Mott cross section at (a) 81, (b) 119, and (c) 162 MeV. The curves represent the spectra predicted by the QRPA. In (b), the open triangles show the spectrum after the E1 contribution has been subtracted.

Coincidence Electron Scattering (e,e'f) and Multipole Strength Functions in ^{238}U

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Lawrence Livermore National Laboratory, Livermore, CA 94550

J. R. Calarco
Department of Physics, University of New Hampshire, Durham, NH 03824

We report excitation functions for $^{238}U(e,e'f)$ from fission threshold to 23 MeV excitation energy for three values of momentum transfer (q = 0.26, 0.40, and 0.55 fm^{-1}). The extracted strength functions for E1 and E2/E0 agree well with those recently calculated with the Quasiparticle Random Phase Approximation (QRPA), except that some E2 strength is apparently missing. E3 and/or higher multipoles clearly contribute a significant amount of cross section throughout the excitation region.